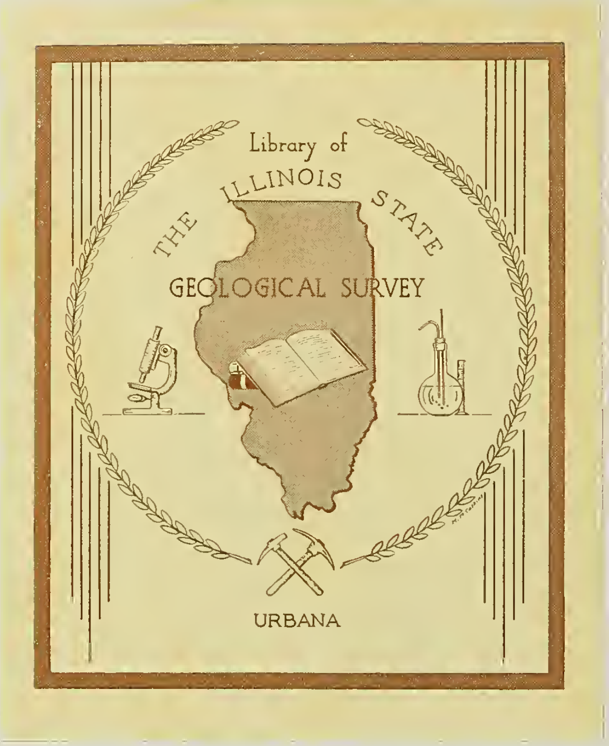

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STUDIES OF LAKE MICHIGAN BOTTOM SEDIMENTS—NUMBER TEN

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Depositional Patterns, Facies, and Trace Element Accumulation in the Waukegan Member of the Late Pleistocene Lake Michigan Formation in Southern Lake Michigan

Jerry A. Lineback and David L. Gross

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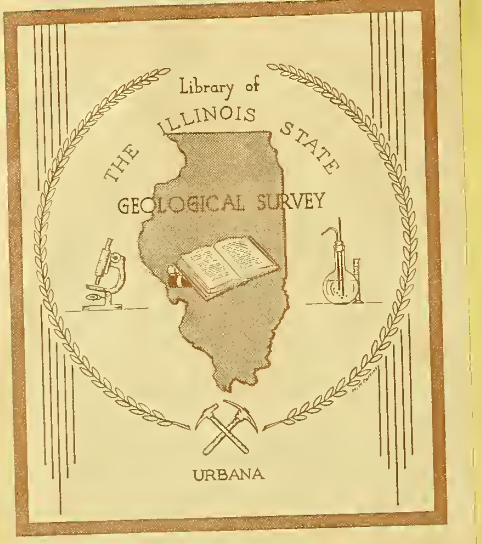

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STUDIES OF LAKE MICHIGAN BOTTOM SEDIMENTS—NUMBER TEN

DEPOSITIONAL PATTERNS, FACIES, AND TRACE ELEMENT ACCUMULATION IN THE WAUKEGAN MEMBER OF THE LATE PLEISTOCENE LAKE MICHIGAN FORMATION IN SOUTHERN LAKE MICHIGAN

Jerry A. Lineback and David L. Gross

ABSTRACT

The Waukegan Member of the Lake Michigan Formation consists mainly of dark clayey silt and silty clay. It underlies Lake Michigan in most of the southern lake basin south of the Mid-lake High. The Waukegan is divisible into two major facies—the gray silt facies that lies in the center and along the eastern side of the southern lake basin, and the brown silt facies that is found along the western side of the lake and along the Mid-lake High. Radiocarbon dates show the Waukegan to be Holocene (late Pleistocene) in age.

The Waukegan is several times thicker in a narrow westward-sloping belt along the eastern shore of Lake Michigan than it is over the remainder of the southern lake basin. Combined sediment coring and high-resolution seismic profiling showed the thickening of the Waukegan begins about 5 miles (8 km) off shore and extends to about 19 miles (30 km) off shore. The belt of thick Waukegan extends continuously from Michigan City, Indiana, northward past Grand Haven, Michigan. The Waukegan is thickest on the middle part of the slope, giving the appearance of a delta-like foreset slope in cross section. The Waukegan thins basinward towards the lower part of the slope (bottomset beds), as well as towards the shore in the shallow water (topset beds).

		Fm.	Member	Description
PLEISTOCENE SERIES	HOLOCENE STAGE	LAKE MICHIGAN	Ravinia	Sand on beaches
			Waukegan	Dark gray to brown, soft sandy silt to silty clay; sand
	?		Lake Forest	Dark gray silty clay with black beds and mottling; more compact than Waukegan Member
	WISCONSINAN STAGE		Winnetka	Dark brownish gray clay; a few black beds and some black mottling
			Shebaygon	Reddish brown clay
			Wilmette Bed	Dark gray clay with some black beds
				Reddish brown clay
			South Haven	Reddish gray clay
	Unnamed	EQUALITY	Cormi	Gray, sandy, pebbly clay; clay; silt; clay-pebble conglomerate
		WEDRON	Unnamed	Reddish brown, silty, clayey till
			Wadsworth	Gray, silty, clayey till

Fig. 1 - Late Pleistocene sediments underlying southern Lake Michigan.

The thick belt of Waukegan indicated the rate of sedimentation along the east side of Lake Michigan was higher than along the west. The sediments were contributed by shoreline erosion and by several small rivers that drain southern Michigan. The belt of Waukegan formed when the clay and silt components of the sediment load were carried out of the nearshore shallow waters and deposited on a pre-existing, basinward-dipping slope, which initially had been formed by glacial erosion and deposition of till. The deposition of the Waukegan Member caused the slope to prograde basinward in a manner analogous to the progression of a delta or a prograding depositional slope associated with a sediment-starved basin.

Man-made pollution, indicated by accumulations of certain trace elements, is confined to the topmost sample interval (2 to 3 cm) of the brown silt facies of the Waukegan Member, but it occurs as deep as 0.5 foot (15 cm) in the gray silt facies. The concentration of some trace elements in the surface of the gray silt facies is also consistently higher than in the brown silt facies.

The geographic location of higher trace-element accumulation is geologically controlled, as it occurs in the areas floored by recently deposited fine-grained sediment.

INTRODUCTION

The Waukegan Member (fig. 1) is the surficial member of the Lake Michigan Formation in most of the southern basin of Lake Michigan (south of the Mid-lake High). The Waukegan has been recognized in 112 of 118 stratigraphic cores collected to date. It can also be recognized on the high-resolution, sub-bottom seismic profiles that have been used to determine internal bedding structure and depositional patterns of the Waukegan and other members of the Lake Michigan Formation. A number of summary core descriptions and 20 cross sections derived from the seismic profiles are presented in this report.

The Waukegan Member consists of soft, water-saturated clay and silt with small amounts of sand. Except for the beach sand of the Ravinia Member, the Waukegan has the coarsest average grain size of all members of the formation and averages 8 percent sand, 41 percent silt, and 50 percent clay (n = 51) (Gross et al., 1972). The Waukegan is dark colored, ranging from dark gray to brownish gray and dark brown. It contains thin (1 to 2 mm) beds of black clay and hard yellowish brown silt. The Waukegan is distinguished from the underlying Lake Forest Member (fig. 1) by being coarser grained, softer, and darker, and in having a higher water content and less prominent black beds. The Waukegan has two major facies—the gray silt facies on the east side of the lake and the brown silt facies on the west—and several minor facies distinguished by grain size, color, and prominence of black beds.

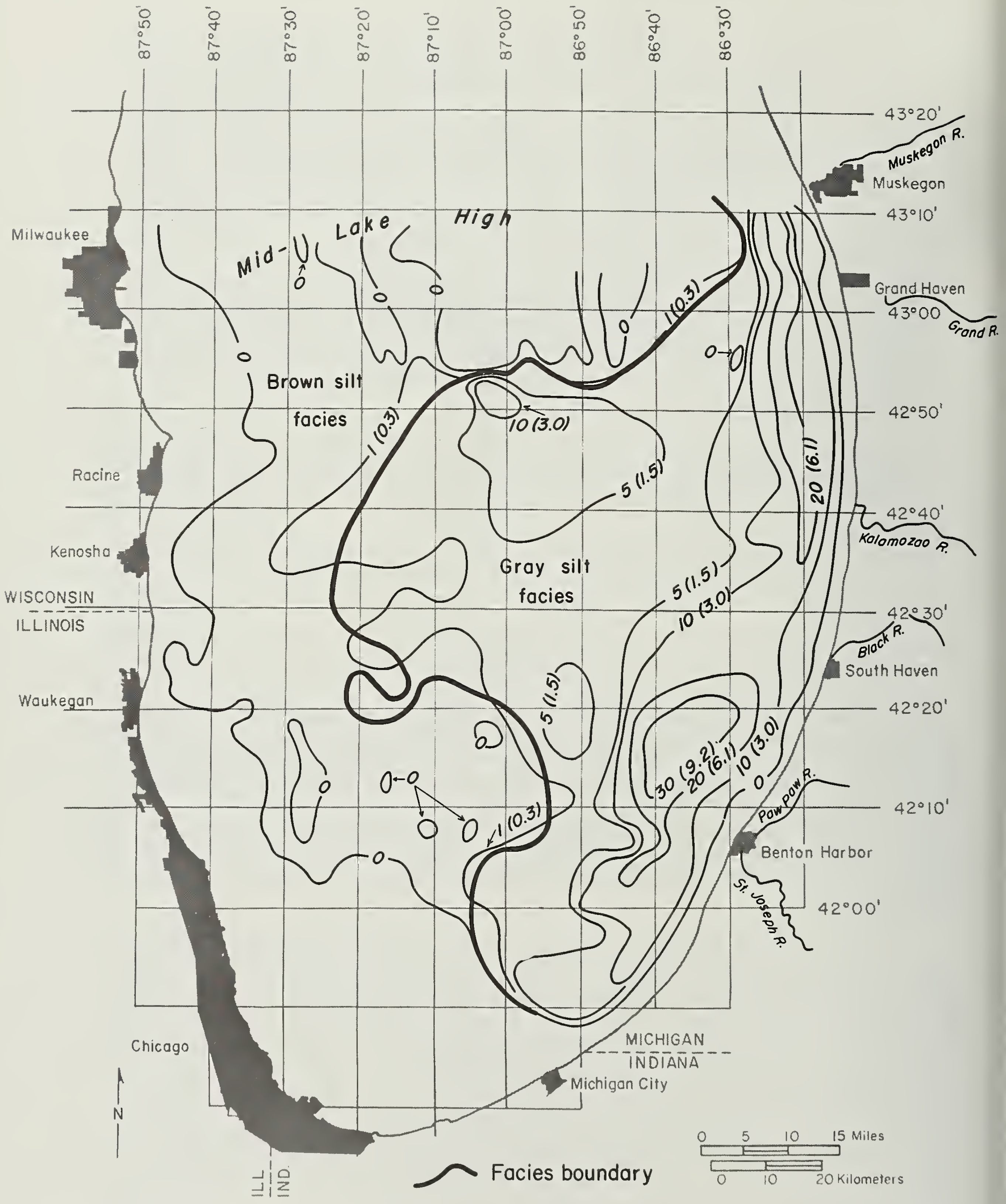

Fig. 2 - Thickness and facies of the Waukegan Member in southern Lake Michigan. Contour interval is 10 feet (3.0 m), but contours at 1 foot (0.3 m) and 5 feet (1.5 m) have been added.

This detailed report on the Waukegan Member is part of a continuing program being conducted by the Illinois State Geological Survey that is designed to describe the geology of southern Lake Michigan. Gross et al. (1970) and Lineback, Ayer, and Gross (1970) discussed the sampling techniques and the preliminary geological interpretations of the southern part of the lake. The use of high-resolution, continuous seismic profiling has provided considerable information on the distribution and structure of the sediments under Lake Michigan (Lineback et al., 1971; Lineback, Gross, and Meyer, 1972). Gross et al. (1972) discussed the grain size and mineralogy of the Pleistocene sediments under the lake. Collinson and Badal (1972) studied the composition of the uppermost few centimeters of the sediment on the lake floor, and their maps include areas where the Waukegan is present. A preliminary version of our report has been given orally by Lineback and Gross (1972).

The coring and geophysical studies were conducted on board the *R. V. Inland Seas*, a research vessel operated by the University of Michigan Great Lakes Research Division under sponsorship of the National Science Foundation. We acknowledge with thanks the aid of Captain Richard Thibault and the crew of the ship during the field studies. The geophysical operations that produced the seismic profiles presented were conducted by Robert P. Meyer and a crew from the Geophysics and Polar Research Center, Department of Geology and Geophysics, University of Wisconsin, Madison. The trace element studies were conducted at the Illinois State Geological Survey by R. R. Ruch, E. J. Kennedy, J. A. Schleicher, D. B. Heck, J. H. Kuhn, and H. V. Leland, under the direction of Neil Shimp.

FACIES OF THE WAUKEGAN MEMBER

Gray Silt Facies

The gray silt facies of the Waukegan (fig. 2) makes up the bulk of the member. It is dark gray (5 Y 4/1)* in most places, but ranges from gray (5 Y 5/1) to black (5 Y 2/1). It is 20 to 40 feet (6 to 12 m) thick in a belt along the eastern shore of the lake (fig. 2). This thick belt of Waukegan extends from Michigan City on the south at least as far as Muskegon. It thins northward and probably ends in the vicinity of Muskegon. It was not found north of Muskegon during a research cruise in October 1972. At most places along the eastern shore of the southern lake basin the till floor of the lake, on which the Lake Michigan Formation was deposited, slopes gently westward from shore for a few miles. The slope then steepens for a further few miles before reaching the deeper water. It is on the steepest part of the slope that the formation is thickest, and half or more of it is the Waukegan Member. Bedding revealed by seismic profiling shows that individual beds in the Waukegan are thickest on the steep slope and that they thin both basinward and shoreward.

The gray silt facies was recognized in 63 cores. The facies extends westward from the eastern shore, past the center of the lake, but it is less

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* All colors given in this report are from Munsell Soil Color Charts and are described from fresh surfaces of wet, newly opened cores.

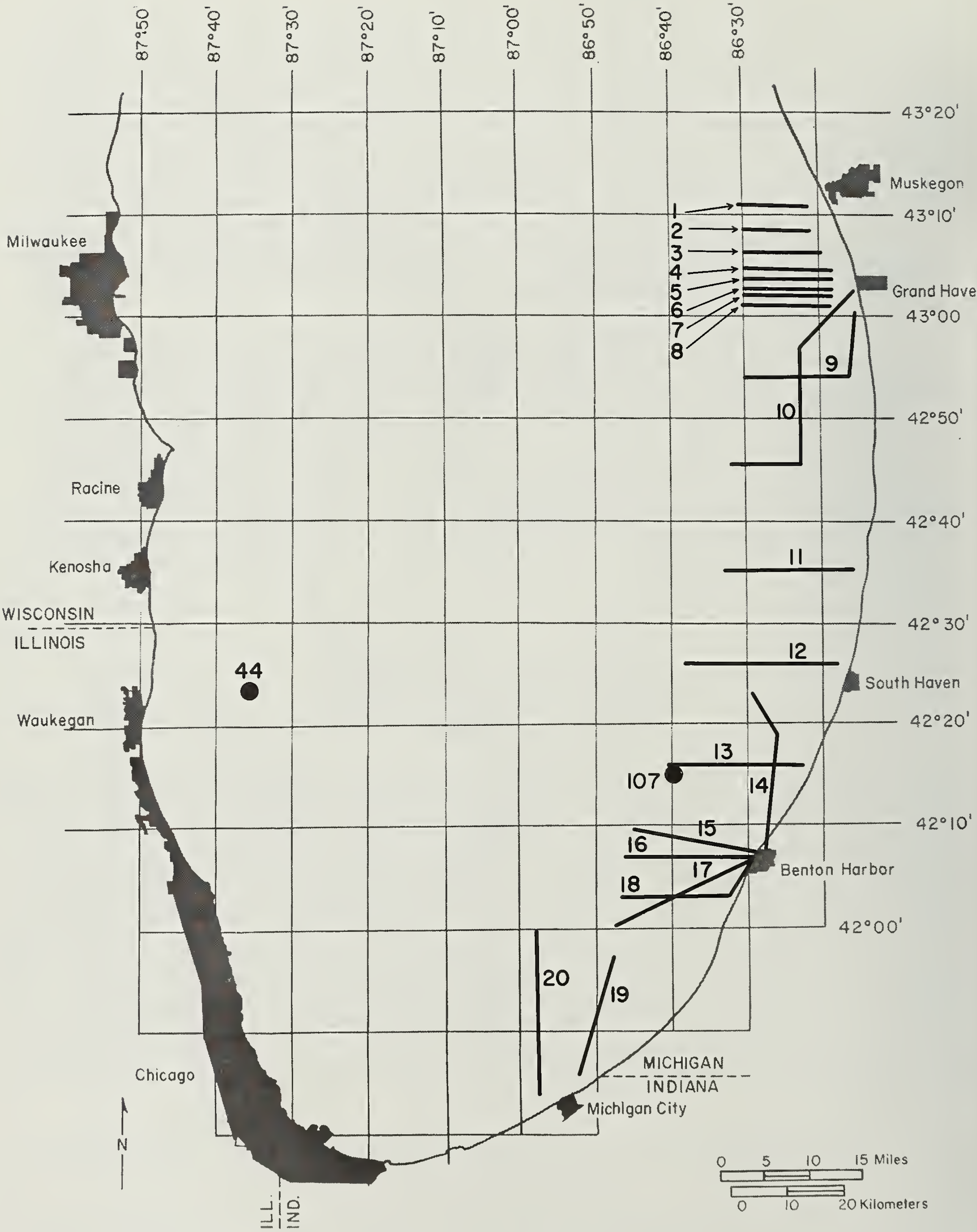

Fig. 3 - Locations of the 20 cross sections that appear in figures 4, 5, and 6, and locations of cores 107 and 44.

than 5 feet (1.5 m) thick in the central part of the southern lake basin. The gray silt facies consists of sediment that decreases in grain size downward from sandy silt to silty clay. The sediment is soft and water saturated, but becomes firmer and has a lower water content downward. Black beds and mottling are present, but the black beds are irregular in thickness and less prominent than similar beds in the underlying Lake Forest Member. Beds of hard, yellowish brown silt, 1 to 2 mm thick, are present in places.

Brown Silt Facies

The other widespread facies of the Waukegan is the brown silt facies (fig. 2). The color varies from grayish brown (10 YR 4/2, 5/3, 4/3, 3/2, and 3/3) to brown (7.5 YR 5/4). The sediment in many places is mottled with lighter and darker brown. The facies is recognized in 37 cores from the southwestern and western parts of the southern lake basin and from along the Mid-lake High. The brown silt facies is generally less than 1 foot (30 cm) thick, much thinner than the gray silt facies. The sediment is similar in grain size and water content to the gray silt facies, but the brown silt is the more clayey. The brown silt contains fewer black beds than the gray silt, but thin, hard, yellowish brown silt beds are present in places.

Other Facies

Minor facies of the Waukegan include sand (3 cores), reddish brown (5 YR 4/6, 5/3) clayey silt (2 cores), dark gray (10 YR 4/1) clayey silt (5 cores) from the area east of Waukegan, and clayey silt of mixed colors (2 cores).

RADIOCARBON DATES

Two radiocarbon dates have been established from the Waukegan Member. A date of 3460 ± 210 radiocarbon years before present (B.P.) (ISGS-68, Lineback et al., 1971) was determined by combining all but the top 5 cm of the Waukegan segment of a core taken near the center of the lake. A wood fragment buried 2.36 feet (72 cm) deep in the gray silt facies of the Waukegan along the eastern side of the lake was dated at 910 ± 140 radiocarbon years B.P. (ISGS-100). Radiocarbon dates of 6920 ± 200 B.P. (ISGS-33) and 7050 ± 200 B.P. (ISGS-36, Lineback, Ayer, and Gross, 1970) from the underlying Lake Forest Member also serve to indicate that the Waukegan Member belongs to the Holocene Stage of the Pleistocene.

SEISMIC PROFILES AND THE GRAY SILT FACIES OF THE WAUKEGAN

High-resolution seismic profiles, taken in 1970, 1971, and 1972, of the sub-bottom of southern Lake Michigan have revealed many details of the stratigraphy of the sediments under the lake. Twenty profiles have crossed the belt along the east side of the lake where the Waukegan is thickest (fig. 3). Acoustically reflecting horizons within the Waukegan and other members are traceable and show the depositional patterns within the units. The cross sections have been numbered consecutively from north to south (fig. 3).

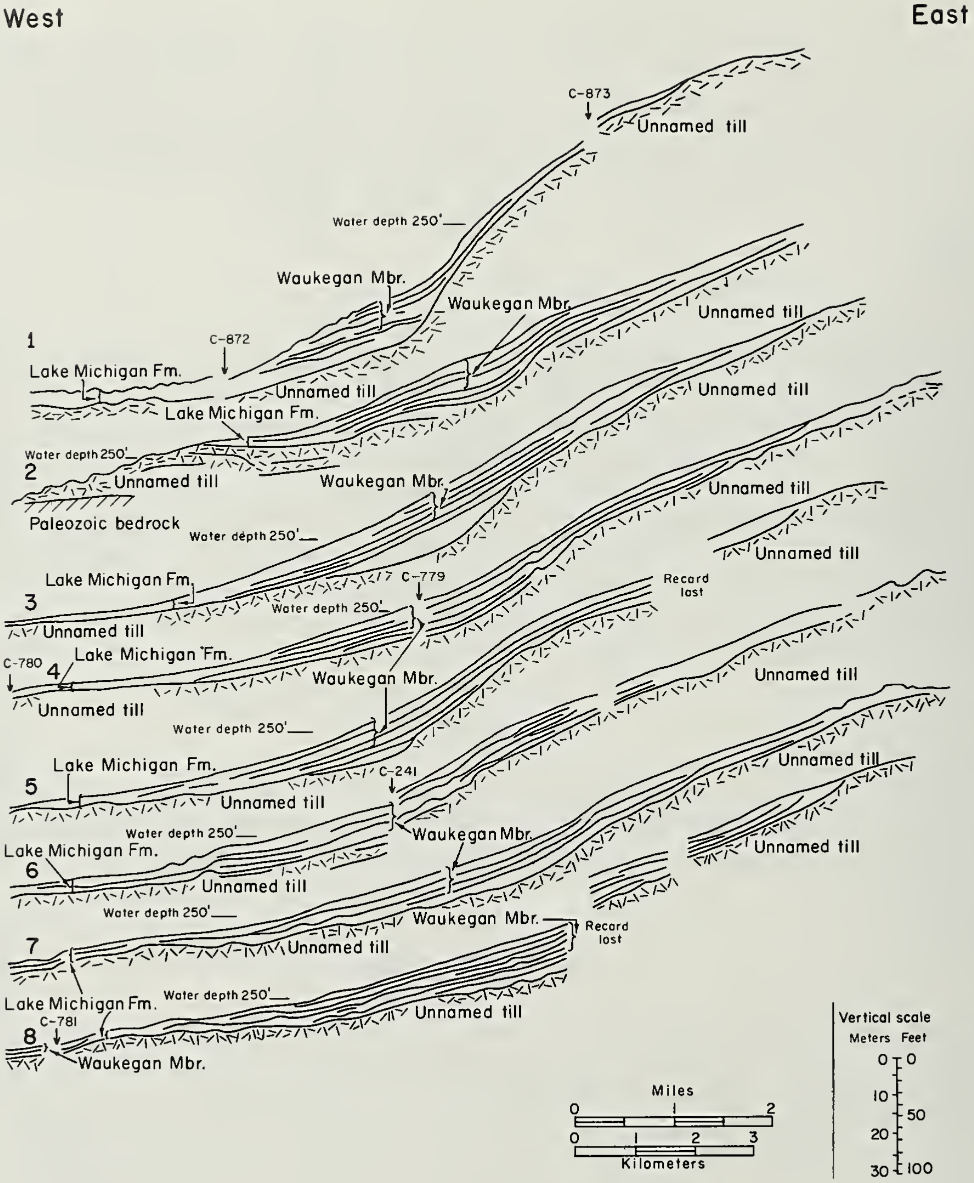

Fig. 4 - Cross sections 1 through 8 show acoustically reflecting horizons in the lake bottom sediments from an area west of Grand Haven and Muskegon. The lines shown on the cross sections are acoustically reflecting horizons traced from high-resolution seismic profiles of the bottom sediments. Stratigraphic interpretations are based on cores and interpretation of the seismic records. Locations of cross sections are shown in figure 3.

Cross sections 1 through 8 (fig. 4) lie on east-west tracks immediately west of Grand Haven and Muskegon. They show some of the details of the gray silt facies. The Lake Michigan Formation is thin near shore but thickens on the steeper part of the slope that descends toward deeper water. The maximum thickness is on the middle or lower part of that slope. When deeper water (250 feet, 76.2 m) is reached, the sediment thins again toward the basin (except in cross section 1). The Waukegan Member makes up most of the Lake Michigan Formation in this area. Core 779 (cross section 4) penetrated 15.05 feet (458 cm) of Waukegan without reaching the base of the member. Core 780, however, had 0.5 feet (15 cm) of Waukegan and only 3.94 feet (120 cm) of Lake Michigan Formation over the Equality Formation and till.

No core in the area where the Waukegan Member is thickest has penetrated any unit below the Lake Forest Member, and most stop in the Waukegan. The Waukegan is as much as 20 feet (6.6 m) thick in the area west of Grand Haven (fig. 2). The remainder of the formation is the Lake Forest Member, although in some places the Winnetka Member may be present. The South Haven and Sheboygan Members pinch out shoreward at water depths of about 270 to 250 feet (88.6 to 76.2 m) and are usually not present on the steep slope where the Waukegan is thickest.

The most northerly cross section (cross section 1) shows the eastern slope of the lake floor to be steeper than it is farther south. The Waukegan is thick near the base of the steep slope. The thick belt of Waukegan probably ends a short distance north of cross section 1. No thick delta-like accumulations of Waukegan were found along the eastern shore near Ludington or Frankfort, Michigan, during a 1972 study.

Cross section 9 (fig. 5) also shows the Lake Michigan Formation thinning shoreward and basinward. The formation is a maximum of 65 feet (21.3 m) thick. Although no cores were taken, the Waukegan, by correlation with other cross sections, composes at least the upper 25 to 30 feet (8.2 to 9.9 m) of the formation.

Part of cross section 10 (fig. 5) lies north-south along the axis of the belt of thick Waukegan and shows the shoreward and basinward thinning of the member in the area southwest of Grand Haven. The same part of the cross section also shows that near-surface reflecting horizons can be traced for several miles and that beds that thin toward shore and toward the basin do not significantly change thickness parallel to shore. Cores 326, 327, and 785 penetrated 10.38 feet (340 cm), 10.19 feet (334 cm), and 7.95 feet (261 cm) of Waukegan, respectively, without reaching its base. An unconformity appears within the Lake Michigan Formation at the western end of the cross section, between the Winnetka and Sheboygan Members. The Lake Michigan Formation above the base of the Winnetka is as much as 50 feet (15.2 m) thick along cross section 10, and the top 25 to 30 feet (8.2 to 9.9 m) is the Waukegan Member. Cross section 10 crosses the area in the southern lake basin where the Lake Michigan Formation is thickest.

About 10 miles (16 km) north of South Haven, cross section 11 (fig. 5) shows that the Lake Michigan Formation is much thinner than it was along the more northerly cross section 10. The entire formation is 25 feet (8.2 m) thick, with the Waukegan Member accounting for 20 feet (6.6 m) of that. The irregular surface of the Paleozoic bedrock appears on this cross section.

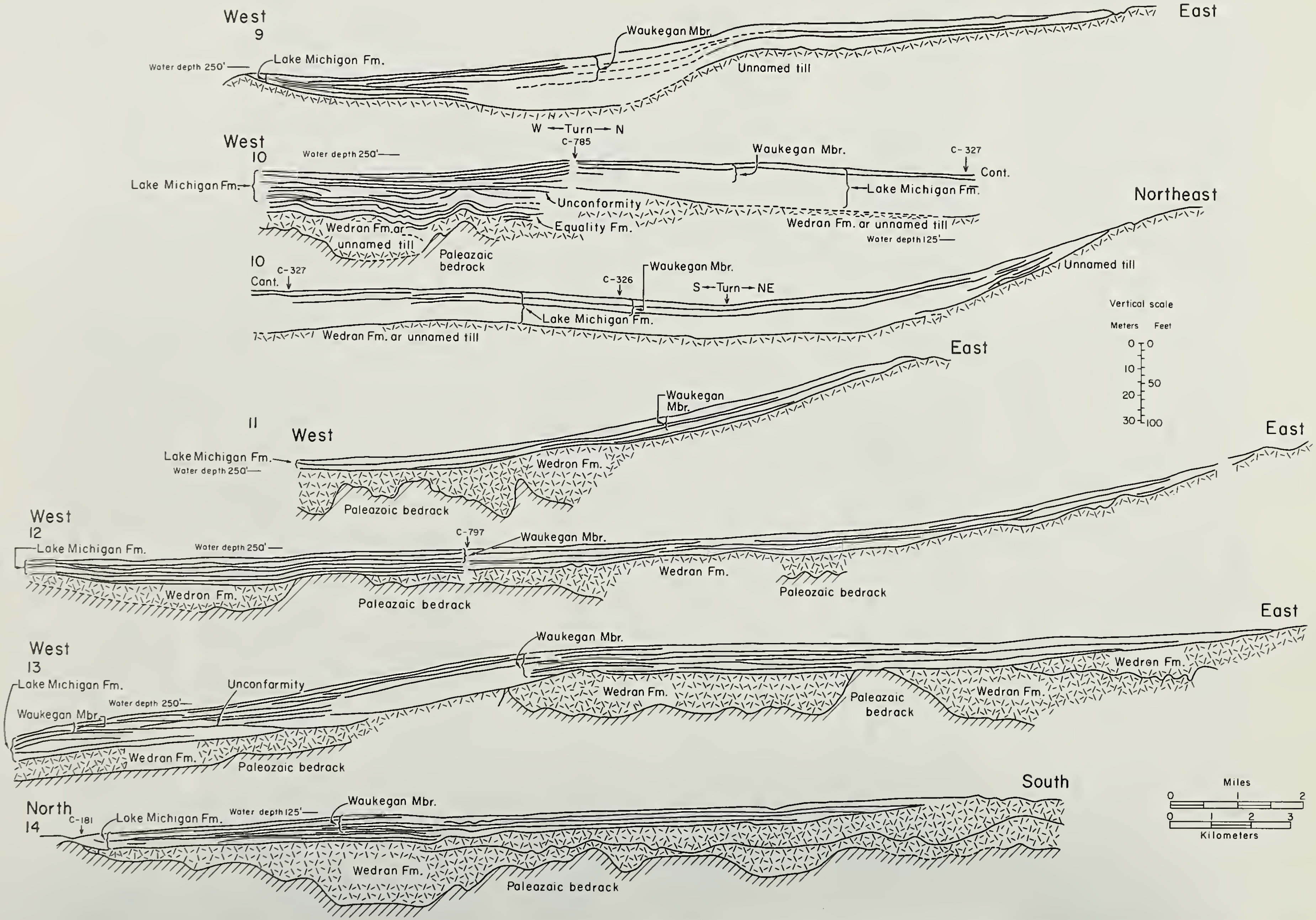

Fig. 5 - Cross sections 9 through 14 show acoustically reflecting horizons in the lake bottom sediments between

Immediately west of South Haven, cross section 12 (fig. 5) shows that the Lake Michigan Formation is thicker (30 feet; 9.9 m) than it is along cross section 11. The Waukegan Member, however, composes only about half of this thickness (16 feet; 3.9 m). Core 797 penetrated 7.24 feet (237 cm) of the Waukegan without reaching the base of the member. The remainder of the formation probably is the Lake Forest and Winnetka Members.

Cross section 13 (fig. 5) shows that halfway between South Haven and Benton Harbor up to 45 feet (14.8 m) of the Lake Michigan Formation is present. The west end of the cross section shows the unconformity between the Sheboygan and Winnetka Members. No cores were taken in this area, but the profiles indicate the Waukegan thickens from less than 3 feet (1 m) at the western end of this cross section to 35 to 40 feet (11.5 to 13.1 m) on the basinward slope. The Waukegan then thins and pinches out shoreward.

A series of five cross sections (14 through 18) radiate out from Benton Harbor (fig. 3). Cross section 14 (fig. 5) extends northward from Benton Harbor parallel to the thick belt of Waukegan. About 30 feet (9.9 m) of sediment is present, 20 feet (6.6 m) of which is assigned to the Waukegan. Core 181 penetrated 7.16 feet (235 cm) of the member without reaching its base. Several reflecting horizons pinch out toward the shore.

Cross section 15 (fig. 6) extends to the northwest from Benton Harbor and shows that nearly 50 feet (16.4 m) of Lake Michigan Formation is present in places. The Waukegan reaches a maximum thickness of 20 feet (6.6 m) on the slope. Due west of Benton Harbor, cross section 16 (fig. 6) shows that the Waukegan thickens from 2.14 feet (70 cm) at core 832 to about 20 feet (6.6 m) on the basinward slope.

Cross section 17 (fig. 6) extends southwest from Benton Harbor. It shows truncation of bedding at the shoreward end of the cross section that resembles large-scale cross bedding or deltaic bedding. It may have originated from a prograding depositional surface or may have resulted from erosional truncation of beds that had a high depositional dip. Cores 188 and 189 penetrated 5.34 feet (175 cm) and 9.73 feet (319 cm), respectively, of Waukegan without reaching the base of the member. The Waukegan is about 20 feet (6.6 m) thick; the remaining 15 feet (4.9 m) of the Lake Michigan Formation is the Lake Forest and Winnetka Members. Because the cross section parallels the depositional strike of the formation, it does not show southwestward thinning.

Cross section 18 (fig. 6) extends southwestward from Benton Harbor a few miles and then westward. It shows inclined bedding at its eastward end similar to that in cross section 17. Core 836 penetrated 6.25 feet (205 cm) and core 837 penetrated 1.8 feet (59 cm) without reaching the base of the Waukegan. The Lake Michigan Formation is 25 to 30 feet (8.2 to 9.9 m) thick, of which the upper 10 to 15 feet (3.2 to 4.9 m) is Waukegan. The Waukegan is thinner in this region and to the south than it is farther north (fig. 2).

The remaining two cross sections (19 and 20, fig. 6) extend northeast and north from Michigan City. Cross section 19 shows that the Lake Michigan Formation is about 30 feet (9.9 m) thick and that it pinches out shoreward. Core 853 penetrated 4.43 feet (135 cm) of Waukegan and 1.64 feet (50 cm) of Lake Forest.

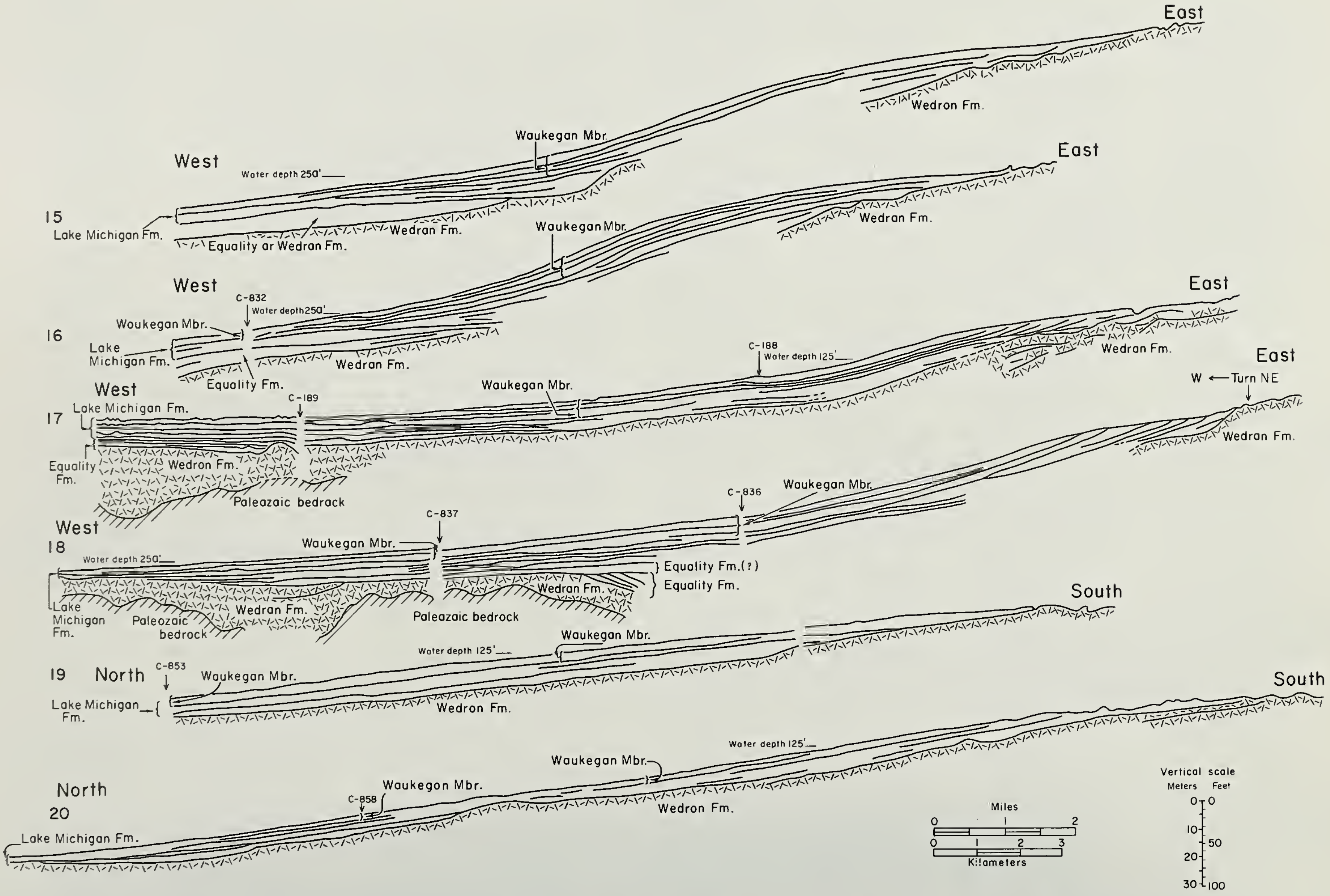

Fig. 6 - Cross sections 15 through 20 show acoustically reflecting horizons in the lake bottom sediments between Benton Harbor and Michigan City. Locations of cross sections are shown in figure 3.

The Waukegan probably reaches a maximum of only 8 feet (2.4 m) thick along the cross section. The remaining part of the formation comprises the Lake Forest and Winnetka Members. These members seem to be thicker in the southeastern corner of the lake than in places farther north.

Cross section 20 shows the Lake Michigan Formation to be less than 25 feet (8.2 m) thick. It thins northward and pinches out shoreward. The Waukegan Member thickens from 2.82 feet (86 cm) in core 858 to about 7 feet (2 m) at its maximum near the middle of the cross section. The Lake Michigan Formation is absent a few miles west of this cross section (fig. 2).

ORIGIN OF THE THICK BELT OF WAUKEGAN

The cross sections through the Waukegan Member of the Lake Michigan Formation along the east side of the lake that have been derived from seismic profiles show a depositional pattern that is due to two factors. The first is the original pre-lake slope formed by the till floor of the lake. This pre-lake topography is a combination of the bedrock configuration and the results of glacial scour and deposition. When the lake had filled to its present level, a narrow shelf was formed in shallow water along the eastern side of the lake. This shelf slopes westward and is bordered on the west by a steeper sloping surface that descends toward the center of the present lake. The eastern shelf is generally less than 90 feet (27 m) below present lake level. The slope descends to a depth of about 250 feet (76 m) before leveling out.

The second factor influencing the depositional pattern is the continuing deposition on the slope. Several small rivers (the Muskegon, St. Joseph, Kalamazoo, and others) empty into Lake Michigan along the eastern side of the lake (fig. 2). Sedimentation rates from this source probably increased during Holocene time as these streams established themselves on the glaciated surface of southern Michigan. The rivers are a source of sediment for the Waukegan Member. Shoreline erosion also may be an effective source of sediment. Coarse sediment (sand) from these sources is deposited near the shore and around the river mouths. The shallow eastern shelf is covered with sand and silty sand that is difficult to penetrate with cores or with the high-resolution seismic equipment used in this study. The fine silt and clay are carried westward toward deeper water. The zone of maximum deposition, indicated by the thickest beds, is on the most steeply dipping part of the slope, which is analogous to the foreset slope of a delta.

The two factors, original slope and continuing deposition on the slope, combine to produce a delta-like cross section in the thick body of Waukegan along the east side of the lake (figs. 4-6). Maximum deposition is on the foreset-like slope, and depositional thinning takes place toward both the topset and bottomset parts. The slope therefore progrades basinward as deposition continues, in a manner analogous to the prograding of a continental slope into a sediment-starved basin.

Sediment distribution is a result of wave-induced currents in shallow water and of lake currents resulting from normal lake circulation. Lake currents have a well established counter-clockwise pattern around the southern basin for most of the year (FWPCA, 1967) and undoubtedly affect the distribution of sediment arriving via the Michigan rivers. The currents may also transport materials from the west side of the lake toward the east and north. The seismic records determine, however, that bedding thickens and thins perpendicular to shore, and beds do not thin noticeably northward parallel to shore, as would be expected if the dominant direction of transport were northward. Near the shore, longshore drift tends to reverse itself, depending on the direction of the wind. In areas along the Michigan shore there is considerable southward longshore movement (Davis, 1970, p. 24). Thus it seems unlikely that large quantities of Waukegan sediments are carried into the area of thick sediment by northward flowing longshore or offshore currents. In addition, the shallow lake floor off Chicago, a possible source area for erosive lake floor currents, is underlain by till or by gravel over till and is not easily erodible. Nor does the longshore transportation of sand in the nearshore zone contribute significantly toward the deposition of the clayey Waukegan.

The exact nature of the transportation of Waukegan sediment from its source several miles across the narrow eastern shelf to deposition on the foreset-like depositional slope is not yet clearly understood, but it is probably accomplished by bottom currents and the settling out of suspended solids. Turbidity currents and downslope slumping of the soft sediments may also be factors, but evidence for these mechanisms has not yet been found in cores or on the seismic profiles. The northward net flow pattern (FWPCA, 1967) may in part account for the parallel alignment of the thick Waukegan Member and the eastern side of the lake basin. No structures analogous to the thick body of Waukegan sediment along the eastern side of the lake have been found along the western side of southern Lake Michigan, because no major rivers flow into the lake there.

GRAY SILT FACIES AND TRACE ELEMENT ACCUMULATION

Studies by Shimp, Leland, and White (1970), Shimp et al. (1971), Kennedy, Ruch, and Shimp (1971), and Ruch, Kennedy, and Shimp (1970) have shown that arsenic, bromine, chromium, copper, lead, zinc, and mercury are up to 20 times mor abundant in the modern surficial sediments (topmost 3 to 5 cm) of southern Lake Michigan than they are in older and deeper sediments in the same cores. In most cores studied, there is a distinct upward increase in the concentrations of these seven trace elements in the modern sediments that is presumed to result from the introduction of materials into the lake by industrial man.

The modern sedimentation rates along the east side of the lake in the gray silt facies of the Waukegan Member are low (rates are not precisely known, but are probably less than 1 mm/yr), although they are higher than those along the west side of the lake. The relatively higher sedimentation rates along the east side of the lake affect the accumulation of these trace elements in the sediment in two ways.

First, the more rapid accumulation causes the increase in trace element abundance to extend deeper in the sediment. In cores from the gray silt facies from the east side of the lake, the point of increase lies as much as 0.5 foot (15 cm) deep (fig. 7) (Shimp, Leland, and White, 1970; Shimp et al., 1971). Cores from along the west side of the lake, where sedimentation is slow, show that the increase in trace elements is confined to about the top inch (2 to 3 cm) of sediment.

Second, there is a distinct geographic distribution of these trace elements. The average concentration of each of these seven trace elements in the topmost sediment (2 to 3 cm) of the gray silt facies is considerably higher than the average concentration of each of the same elements in the topmost sediment of the remainder of southern Lake Michigan (fig. 8).

Shimp, Leland, and White (1970) and Shimp et al. (1971) also reported that seven other trace elements—beryllium, boron, cobalt, lanthanum, nickel, scandium, and vanadium—showed no significant increases in concentration in the uppermost sediment samples from southern Lake Michigan. For these nonaccumulating trace elements, the concentrations at the top of the cores do not differ substantially from the concentrations deeper in the same cores. The seven nonaccumulating trace elements, however, are also present in greater concentrations in the uppermost 2 to 3 cm of sediment of the gray silt facies than in the uppermost sediment of the remainder of southern Lake Michigan (fig. 9). The differences in concentrations between the gray silt facies and concentrations in the uppermost sediments from the rest of the southern lake basin are not so great for the seven nonaccumulating trace elements as they are for the seven accumulating trace elements (table 1). The concentration ratios for the accumulating trace elements in the gray silt facies to the concentrations in the other uppermost sediments range from 1.5 to 3.0 and average 2.2 (table 1). The concentration ratios for the nonaccumulating trace elements in the uppermost sediments of southern Lake Michigan range from 1.2 to 1.5 and average 1.3 (table 1).

The greater abundance of the nonaccumulating trace elements in the gray silt facies of the Waukegan Member indicates that all trace elements are more likely to be deposited with the gray silt than with the brown silt facies. Trace elements are attracted to organic particles and to clay-sized particles, especially the clay minerals, and are deposited with them. As the gray silt facies contains more clay and more organic carbon than the rest of the Waukegan and the other lake floor sediments, it accumulates a high proportion of trace elements.

The greater rate of deposition in the gray silt facies may also preserve the original trace element record by covering it up faster. A lower sedimentation rate affords more time for trace element losses due to exchange diffusion and methylation across the sediment-water interface. Furthermore, a lower deposition rate increases the opportunity for enriched modern sediments to mix with older sediments that have lower trace element concentrations and thus show an apparent decrease in concentration. Such mixing might be caused by current action or bioturbation.

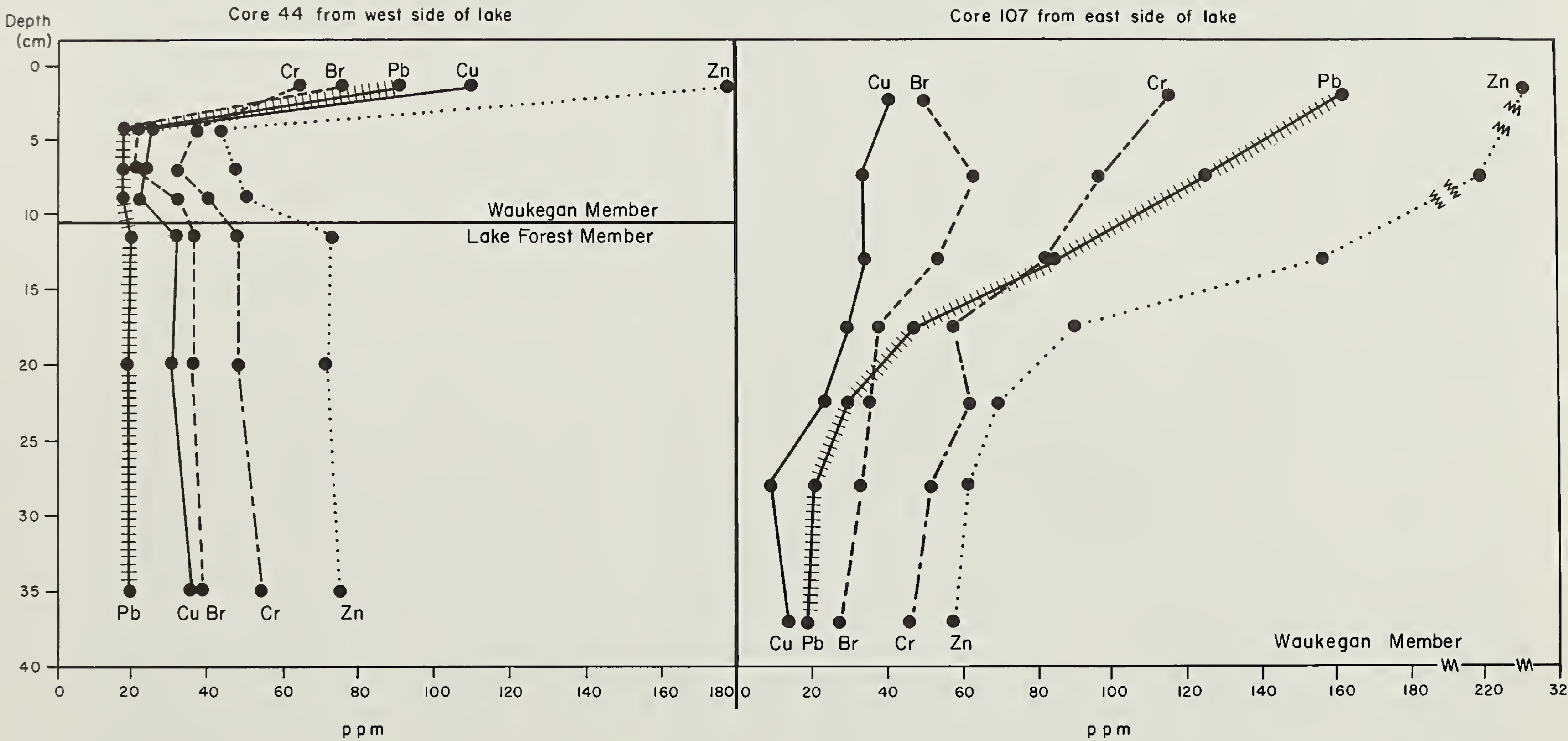

Fig. 7 - Comparison between depth of increase in trace elements in cores from the brown silt facies for the west side of the lake (core 44) and the gray silt facies (core 107) of the east side. The increase in trace element concentrations falls within the topmost sample (0-3 cm) of core 44 but is present to a depth of about 15 cm in core 107. Locations of cores 107 and 44 are shown in figure 3. (Modified from Shimp, Leland, and White, 1970, and Shimp et al., 1971.)

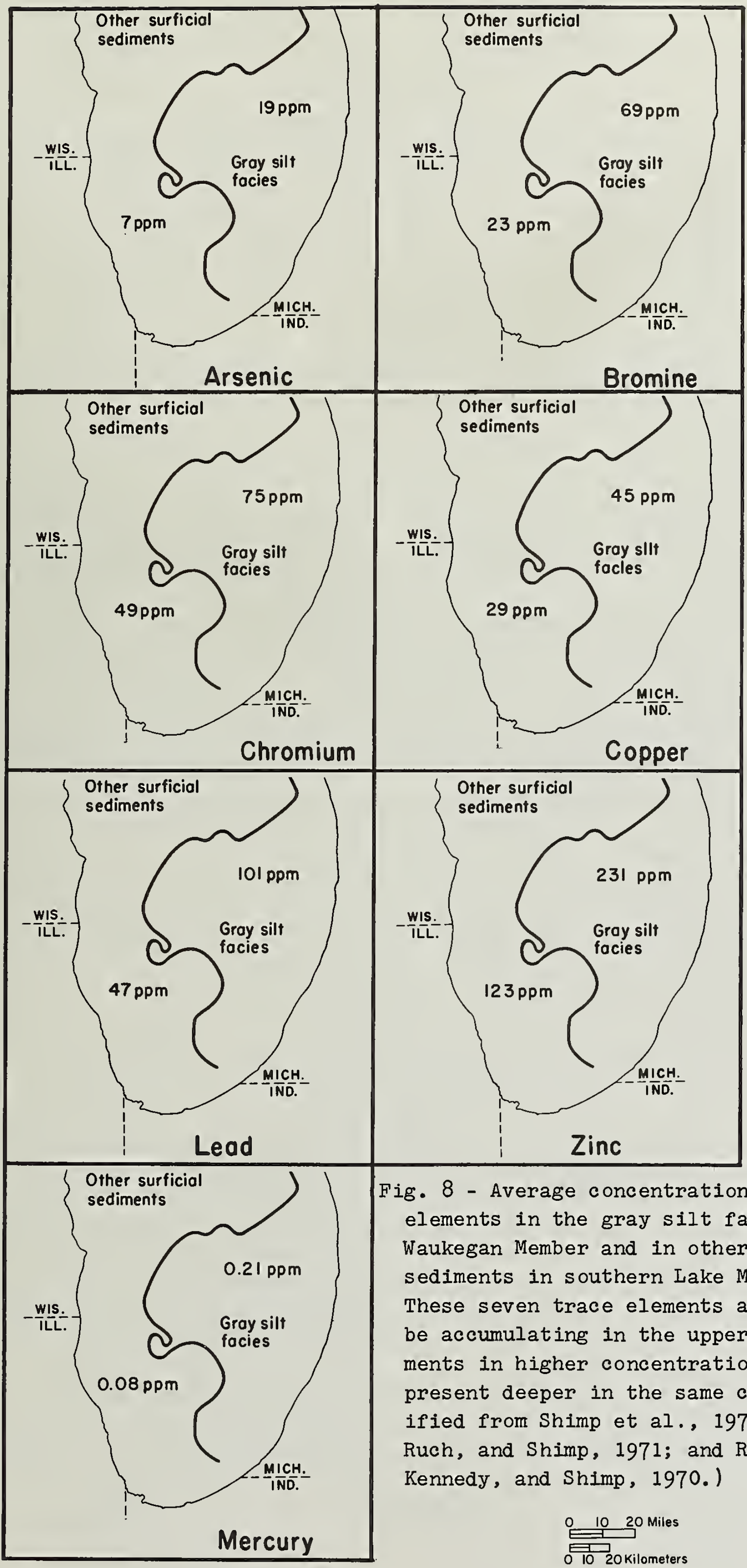

Fig. 8 - Average concentrations of trace elements in the gray silt facies of the Waukegan Member and in other uppermost sediments in southern Lake Michigan. These seven trace elements are known to be accumulating in the uppermost sediments in higher concentrations than are present deeper in the same cores. (Modified from Shimp et al., 1971; Kennedy, Ruch, and Shimp, 1971; and Ruch, Kennedy, and Shimp, 1970.)

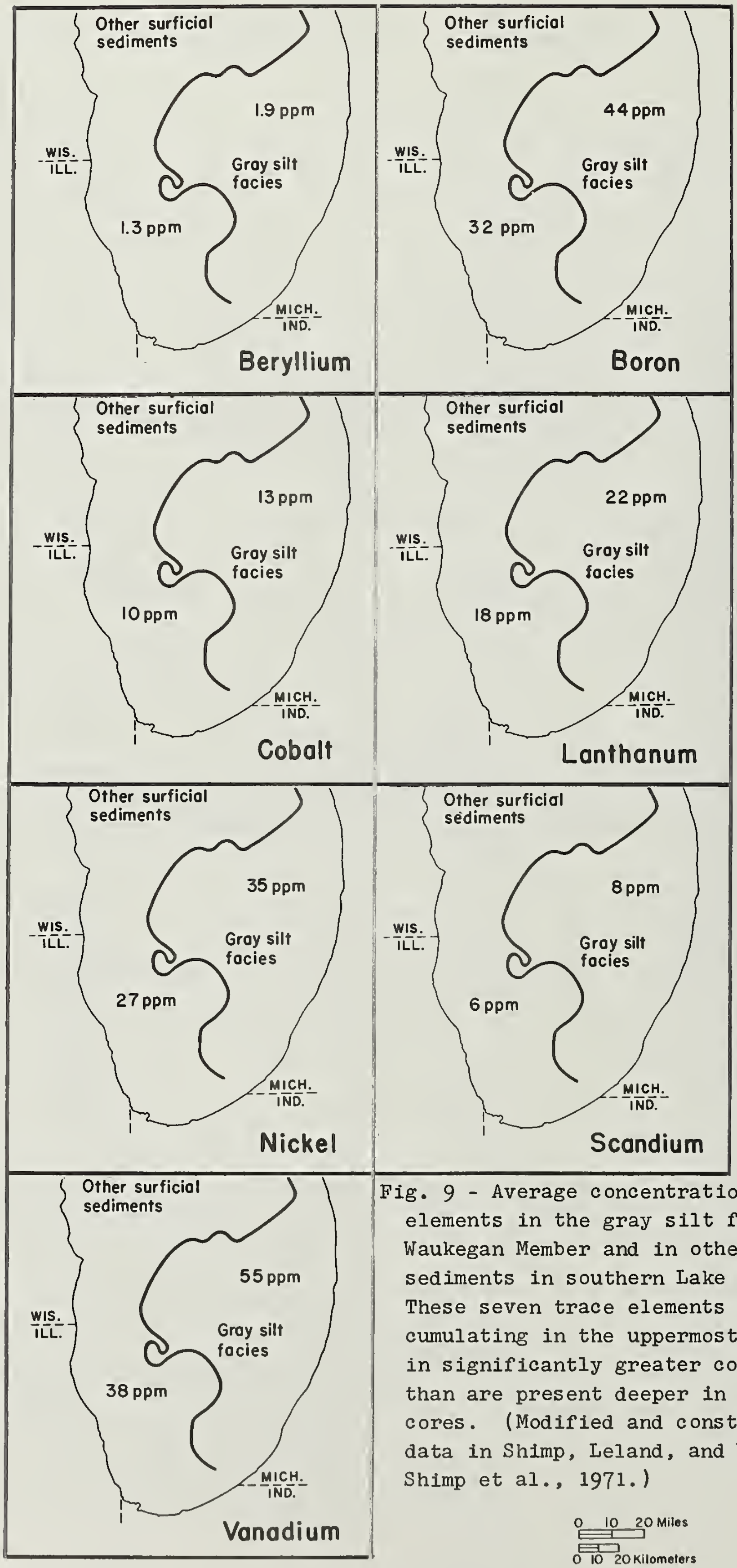

Fig. 9 - Average concentrations of trace elements in the gray silt facies of the Waukegan Member and in other uppermost sediments in southern Lake Michigan. These seven trace elements are not accumulating in the uppermost sediments in significantly greater concentrations than are present deeper in the same cores. (Modified and constructed from data in Shimp, Leland, and White, 1970; Shimp et al., 1971.)

TABLE 1—CONCENTRATIONS OF TRACE ELEMENTS IN UPPERMOST SEDIMENTS OF SOUTHERN LAKE MICHIGAN

Concentrations of accumulative trace elements

Trace element	Gray silt facies av. (ppm)	Other uppermost sediments av. (ppm)	Ratio of concentrations gray silt/other
As	19	7	2.7
Br	69	23	3.0
Cr	75	49	1.5
Cu	45	29	1.6
Pb	101	47	2.2
Zn	231	123	1.9
Hg	0.21	0.08	2.6

Concentrations of nonaccumulative trace elements

Trace element	Gray silt facies av. (ppm)	Other uppermost sediments av. (ppm)	Ratio of concentrations gray silt/other
Be	1.9	1.3	1.5
B	44	32	1.4
Co	13	10	1.3
La	22	18	1.2
Ni	35	27	1.3
Sc	8	6	1.3
V	55	38	1.4

DISCUSSION

As the sampling points were chosen before the existence of the gray silt facies was known, the sampling plan was not fully adequate for testing the theories expounded here, so that there is considerable bias in the data. Still, it is obvious that the distribution and concentration of trace elements in southern Lake Michigan is affected by the geology of the basin—the bottom topography, the distribution of bedrock, till, and lacustrine sediments, the modern sedimentation rates, and the depositional patterns.

The sediment of the gray silt facies is derived from erosion of the southeastern and eastern shores of the lake and from the rivers that drain southern Michigan. Those rivers are one of the major contributors of the waterborne trace element pollutants entering the southern lake basin. However, the presence of high concentrations of trace elements in the gray silt facies of southeastern Lake Michigan does not prove that the eastern side of the lake is the only source of such pollutants. The fact that the most rapid accumulation of fine-grained sediments is occurring in the gray silt facies dictates that the trace element pollutants from any source will be deposited in the gray silt areas, because trace elements tend to be attracted to and deposited with clay-sized particles, particularly clay minerals and organic particles. It is entirely possible that trace elements entering the lake from other areas or through other mechanisms (e.g., atmospheric sources) will be transported to the eastern side of southern Lake Michigan and eventually be deposited in greatest abundance in the fine-grained sediments of the gray silt facies of the Waukegan Member.

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APPENDIX

SUMMARY CORE DESCRIPTIONS

The following summary descriptions are of gravity cores, 1 7/8 inch (47 mm) in diameter, collected during various cruises on the *R. V. INLAND SEAS* along the cross sections illustrated in this report. Cores 872 and 873 have not yet been described. All other cores have been described in detail in the publications indicated. Colors given are those of the standard Munsell notation.

CORE 181

Lat. 42°22.4'N, long. 86°30.6'W;
water depth 168 feet (51.2 m)
(Lineback et al., 1971).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Clay, silty, dark gray; trace of sand; faint bedding; 5 Y 4/1	235.0

CORE 188

Lat. 42°03.2'N, long. 86°40.8'W;
water depth 146 feet (44.5 m)
(Lineback et al., 1971).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Silt, black to dark gray; faint bedding; 5 Y 2/1 to 5 Y 4/1	175.0

CORE 189

Lat. 42°00.2'N, long. 86°49.1'W;
water depth 187 feet (57.0 m)
(Lineback et al., 1971).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Silt, dark gray; becomes more clayey downward; faint bedding and some black mottling; 5 Y 4/1	319.0

CORE 241

Lat. 43°03.0'N, long. 86°22.3'W;
water depth 212 feet (64.6 m)
(Lineback et al., 1971.)

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Silt, sandy, dark gray; black beds and mottling; 5 Y 4/1	266.0

CORE 326

Lat. 42°56.8'N, long. 86°23.2'W;
water depth 219 feet (66.8 m)
(Lineback, Gross, and Meyer, 1972).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Clay, silty, dark gray; trace of sand; faint black beds and mottling; 5 Y 4/1	340.0

CORE 327

Lat. 42°52.5'N, long. 86°23.2'W;
water depth 215 feet (65.5 m)
(Lineback, Gross, and Meyer, 1972).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Clay, silty, dark gray; faint black beds and mottling; 5 Y 4/1	334.0

CORE 779

Lat. 43°04.7'N, long. 86°28.8'W;
water depth 232 feet (70.7 m)
(Lineback, Gross, and Meyer, 1972).

Pleistocene Series	Depth (cm)
Lake Michigan Formation	
Waukegan Member	
1. Silt, clayey, dark gray to gray; faint black beds and mottling; 5 Y 4/1 to 5/1 . .	458.0

CORE 780

Lat. 43°04.7'N, long. 86°29.8'W;
water depth 297 feet (90.5 m)
(Lineback, Gross, and Meyer, 1972).

Pleistocene Series	Depth (cm)
Lake Michigan Formation	
Waukegan Member	
1. Sand, clayey, brown; brown mottling; 10 YR 4/3	14.7
Lake Forest Member	
2. Clay, sandy, gray; black mottling; sand at base; 10 YR 5/1	75.5
South Haven Member	
3. Clay, reddish brown; very faint bedding; beds of gray silt in lower part; 5 YR 5/3	120.0
Equality Formation	
Carmi Member	
4. Clay, silty, brown to grayish brown, hard, firm; trace of sand and pebbles; bedding distorted; 7.5 YR 5/2 to 10 YR 5/2	208.0
Unnamed formation	
5. Till, clayey, brown; trace of silt, sand, and pebbles; 7.5 YR 5/2	212.0

CORE 785

Lat. 42°45.0'N, long. 86°23.0'W;
water depth 227 feet (99.2 m)
(Lineback, Gross, and Meyer, 1972).

Pleistocene Series	Depth (cm)
Lake Michigan Formation	
Waukegan Member	
1. Silt, clayey, dark gray; faint black beds and black mottling; 5 Y 4/1	261.0

CORE 797

Lat. 42°25.0'N, long. 86°34.0'W;
water depth 206 feet (62.8 m)
(Lineback, Gross, and Meyer, 1972).

Pleistocene Series	Depth (cm)
Lake Michigan Formation	
Waukegan Member	
1. Silt, clayey, dark gray; trace of sand; faint bedding and black mottling; 5 Y 4/1	237.0

CORE 832

Lat. 42°07.7'N, long. 86°45.8'W;
water depth 257 feet (78.3 m)
(Lineback, Gross, and Meyer, 1972).

Pleistocene Series	Depth (cm)
Lake Michigan Formation	
Waukegan Member	
1. Silt, sandy, dark gray; becomes clayey downward; black beds and mottling; 5 Y 3/1 to 4/1	70.2
Lake Forest Member	
2. Clay, gray; trace of silt and sand; black beds and mottling; 10 YR 5/1	99.5

Winnetka Member

3. Clay, sandy; brownish gray; faint black beds; 10 YR 5/2	242.0

CORE 836

Lat. 42°02.7'N, long. 86°43.5'W;
water depth 182 feet (55.5 m)
(Lineback, Gross, and Meyer, 1972).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Silt in upper part, clay in lower part; trace of sand; faint bedding; faint black beds; 5 Y 4/1	205.0

CORE 837

Lat. 42°02.7'N, long. 86°48.2'W;
water depth 223 feet (68.0 m)
(Lineback, Gross, and Meyer, 1972).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Silt, dark gray; trace of sand; 5 Y 4/1	59.0

CORE 853

Lat. 41°57.7'N, long. 86°48.7'W;
water depth 170 feet (51.8 m)
(Lineback, Gross, and Meyer, 1972).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Silt, clayey, dark gray; trace of sand; faint black beds in lower part; 5 Y 4/1	185.0

CORE 858

Lat. 41°57.7'N, long. 86°57.5'W;
water depth 197 feet (60.0 m)
(Lineback, Gross, and Meyer, 1972).

Pleistocene Series Lake Michigan Formation Waukegan Member	Depth (cm)
1. Silt, clayey, very dark gray; trace of sand; faint bedding; 5 Y 4/1	86.0
Lake Forest Member	
2. Clay, gray; faint black beds and mottling; 10 YR 5/1	148.0

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